Relationships between fish size and otolith morphology in ten clupeids from the Persian Gulf and Gulf of Oman

by

Tooraj VALINASSAB* (1), Jafar SEIFABADI (2), Hanie HOMAUNI (2)
& Mohammad-Ali AFRAIE BANDPEI (1)

ABSTRACT. - The relationships between sagitta otolith morphometry (length, height, and weight) and fish size (standard length and weight) were examined for ten species of clupeids in the Persian Gulf and Oman Sea. We provide new information regarding otolith morphology and body size relationships of these clupeids. Statistical tests to examine correlation between left and right otolith dimensions showed no significant differences. Regression models relating each otolith morphometric parameter to fish length are provided. According to the morphometric relationships obtained, we concluded that length and weight of otolith are good indicators for fish standard length and weight in all the sampled species.

RÉSUMÉ. - Relations entre la taille du poisson et la morphologie des otolithes chez dix clupéidés du golfe Persique et du golfe d'Oman.

Les relations entre des paramètres morphométriques des otolithes sagitta (longueur, hauteur et poids) et la taille des individus (longueur standard et poids) ont été examinées pour dix espèces de clupéidés dans le golfe Persique et le golfe d'Oman. Des tests statistiques ont été réalisés pour examiner la différence de corrélation entre les otolithes droits et gauches : aucune différence statistiquement significative n'a été observée. Des modèles de régression sont fournis concernant chaque paramètre morphométrique des otolithes par rapport à la longueur des poissons. L'analyse des relations morphométriques indique que la longueur et le poids des otolithes sont de bons indicateurs de la longueur standard et du poids du poisson pour toutes les espèces échantillonnées.

Key words. - Clupeidae - Persian Gulf - Gulf of Oman - Otolith - Length-weight relationships.

The inner ear of teleosts contains a left and right membranous labyrinth enclosed in bony otic capsules at the rear of the neurocranium. The labyrinth includes three compartments: the utriculus, sacculus and lagena. Each compartment contains an otolith: the lapillus, sagitta, and asteriscus, respectively (Berra and Aday, 2004). Otoliths have an important biological function because they enable the inner ear to mediate the senses of hearing and balance (Popper *et al*., 2005). Otoliths are composed of calcium carbonate, generally in the form of aragonite, arranged in a laminar form in a protein matrix. Otoliths are commonly used to determine the taxon, age, and size of fishes. This information is useful for population management, predator-prey studies, and archaeological research (Harvey *et al*., 2000).

Paleontologists, archaeologists and oceanographers have recovered otoliths in sediments and have determined species of fishes from otoliths (e.g. Fitch, 1968, 1969; Casteel, 1974; Béarez, 2000). Diets of marine predators have been described using otoliths collected from samples (stomachs, faeces, regurgitates) of piscivorous fishes, marine birds and marine mammals (Harvey *et al*., 2000).

Trout (1954) Templemann and Squires (1956) were among the first to demonstrate a significant positive relationship between otolith size and fish size of Barents Sea cod (*Boreogadus saida*) and haddock (*Melanogrammus aeglefinus*). Otolith length also has been correlated with fish weight (Casteel, 1976). Since these early studies, relationships between otolith length and fish length have been generalized for fish species, including for example, North Pacific gadids (Frost and Lowry, 1981), rockfishes (Wyllie-Echeverria, 1987), or fishes off Baja California (Gamboa, 1991).

The present study focuses on the saccular otolith (sagitta), which is the largest and/or most massive of the three types of otoliths in most groups of teleosts (Nolf, 1985; Assis, 2005), including clupeids. The objective was to compile information regarding the relationship between otolith morphometrics and fish size for 10 species of clupeids in the Persian Gulf and the Gulf of Oman. These data may be used to determine original prey size (body length and body weight) from length, height and/or weight of isolated otoliths.

MATERIAL AND METHODS

Ten species of Clupeidae were studied, namely chacunda gizzard shad (*Anodontostoma chacunda*), rainbow

---

(1) Iranian Fisheries Research Organization, P.O. Box: 14155-6116, Tehran, Iran. [mafraei@yahoo.com]
(2) Faculty of Marine Science, Tarbiat Modarres University, Noor city, Iran. [jseyfabadi@gmail.com] [homaioni@yahoo.com]
* Corresponding author [t_valinassab@yahoo.com]

Cybium 2012, 36(4): 505-509.

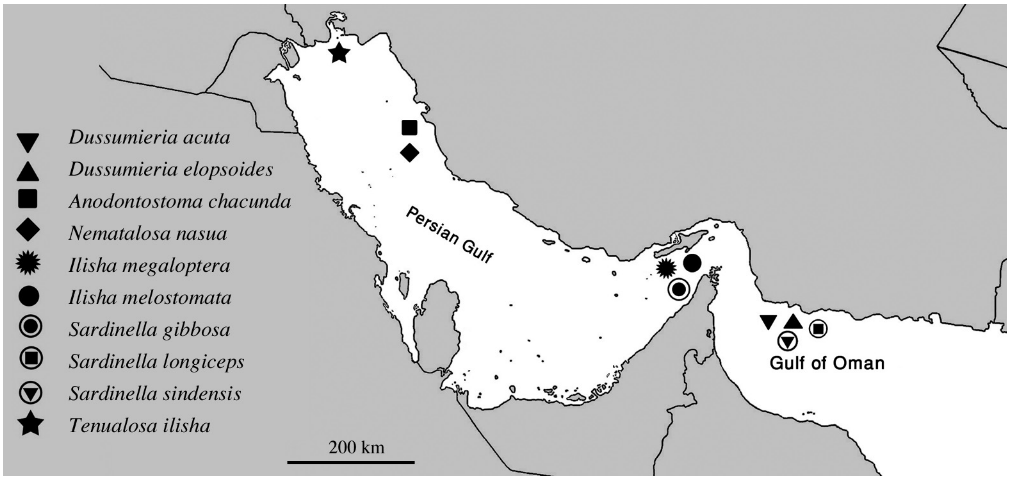

Figure 1. - Sampling sites for the 10 clupeid species in the Persian Gulf and the Gulf of Oman.

Table I. - Sample sizes of 10 clupeid species in the Persian Gulf and the Gulf of Oman.

Species	N	Standard length range (mm)	Mean standard length (mm)	Weight range (g)	Mean weight (g)
Anodontostoma chacunda	37	100-150	130.8 ± 6.8	35-90	70.8 ± 3.54
Dussumieria acuta	37	82-116	95.0 ± 4.73	8-25	13.5 ± 0.67
Dussumieria elopsoides	40	120-150	135.5 ± 12.53	20-40	33 ± 1.65
Ilisha megaloptera	30	215-360	311.6 ± 15.58	135-595	386.1 ± 19.3
Ilisha melastoma	30	130-220	189.3 ± 9.46	32-152	106.4 ± 5.32
Nematolosa nasus	30	75-95	84.3 ± 4.21	10-20	15.5 ± 0.75
Sardinella gibbosa	40	100-140	121.0 ± 6.5	20-35	26.8 ± 1.34
Sardinella longiceps	30	120-155	146.0 ± 7.3	25-50	37 ± 1.85
Sardinella sindensis	40	85-120	99.7 ± 4.94	8-18	12.4 ± 3.02
Tenualosa ilisha	30	245-314	272.0 ± 11.12	265-700	386.5 ± 19.32

sardine (*Dussumieria acuta*), slender rainbow sardine (*D. elopsoides*), bigeye ilisha (*Ilisha megaloptera*), Indian ilisha (*I. melastoma*), Bloch's gizzard shad (*Nematolosa nasus*), goldstripe sardinella (*Sardinella gibbosa*), Indian oil sardine (*S. longiceps*), Sind sardinella (*S. sindensis*), and hilsa shad (*Tenualosa ilisha*). Fish samples were caught by beach seine net during fishing research cruises in the Persian Gulf and the Gulf of Oman in autumn 2008 (Fig. 1); samples were frozen in the field, then thawed in the laboratory where fishes were identified following keys provided by FAO (Fischer and Bianchi, 1984). Body weight (BW) of the fishes was measured with 0.01 g precision and the fish standard length (SL) measurements were recorded with 1 mm precision. The sagittae were removed, cleaned, dried and stored in glass vials for subsequent examination. Total otolith weight (OW) was measured using an electronic balance with 0.1 mg sensitivity (Tab. I). Otolith length (OL) is defined as the longest dimension between the anterior and posterior edges of the otolith, and otolith height (OH) as the dimension from the dorsal to ventral edge (Fig. 2).

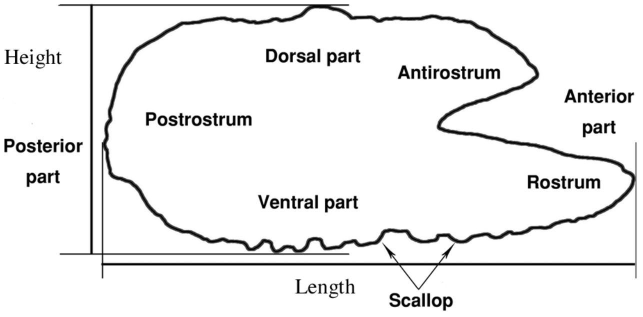

Figure 2. - Anatomy and morphometry of the clupeid sagitta.

Both left and right otoliths were photographed (in medial and lateral view) on a dark background by a digital camera connected to a stereomicroscope (Fig. 3). Otolith length and height in high contrast images were measured by Image J software developed by W. Rasband at the NIH (freely available at http://rsb.info.nih.gov/ij/). The left and right otoliths were considered separately, using a paired t-test to differentiate between right and left ones. Since no significant differ-

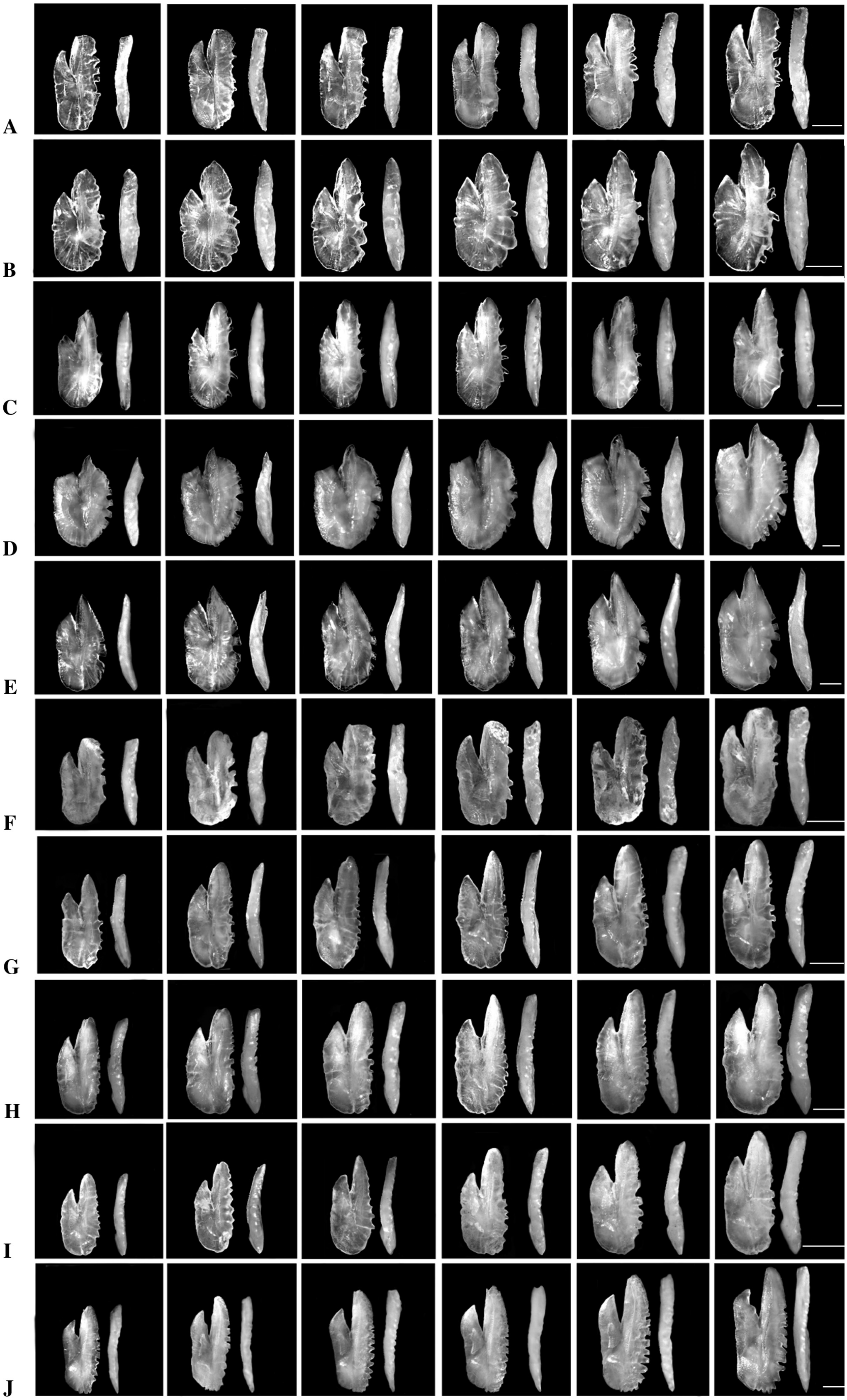

Figure 3. - Medial and dorsal views of left sagittae viewed under a dissection microscope at 6X magnification. Morphological variation with size among different species: *A. chacunda* (**A**), *D. acuta* (**B**), *D. elopsoides* (**C**), *I. megaloptera* (**D**), *I. melostoma* (**E**), *N. nasus* (**F**), *S. gibbosa* (**G**), *S. longiceps* (**H**), *S.sindensis* (**I**), and *T. ilisha* (**J**). Scale bars = 1 mm.

ences between left and right otoliths were observed, only left ones were used in our analyses.

The following morphometric relationships were analyzed: BW vs SL; OL vs SL; OH vs SL; OW vs SL; OL vs BW; OW vs BW; and OH vs BW. Morphometric relationships were built using exponential regression models, which best fit the data distribution. Differences between right and left sagittae were tested using a paired t-test. When the equations for left and right otoliths did not differ statistically, left otolith was selected for each individual species.

Table II. - Relationships between fish length and body weight in 10 clupeids from the Persian Gulf and the Gulf of Oman. Coefficient of determination (R^2). All regressions statistically significant at $p < 0.05$.

Species	N	W vs. SL	R^2
A. chacunda	37	$W = 0.00002SL^{3.077}$	0.938
D. acuta	37	$W = 0.00002SL^{2.922}$	0.927
D. elopsoides	40	$W = 0.0001SL^{2.775}$	0.861
I. megaloptera	30	$W = 0.00007SL^{2.694}$	0.939
I. melostoma	30	$W= 0.00004SL^{2.829}$	0.957
N. nasus	30	$W =0.000007SL^{3.281}$	0.945
S. gibbosa	40	$W = 0.0001 SL^{2.792}$	0.787
S. longiceps	30	$W = 0.001SL^{3.169}$	0.816
S. sindensis	40	$W = 0.00005 SL^{3.088}$	0.879
T. ilisha	30	$W = 0.00002 SL^{3.013}$	0.872

RESULTS

No significant differences in all morphometric parameters between left and right otoliths were observed, except for OL in *A. chacunda* and *N. nasus*. The relationship between SL and BW was described (Tab. II). Analyses of otolith morphometric parameters vs standard length and body weight showed that otolith length and otolith weight were good indicators of fish size. The relationships between morphometric parameters, SL and BW were described by the linear regression model, which nearly explained 80% of variance expect for *T. ilisha* (Tabs III, IV).

DISCUSSION

In this study, no statistically significant difference between left and right otoliths was observed in the 10 spe-

Table III. - Relationship between sagitta morphometric parameters and standard length (SL). Coefficient of correlation (R). OL: otolith length, OH: otolith height, OW: otolith weight. All regressions were statistically significant at $p < 0.05$.

Species	N	OL vs. SL	R^2	OH vs. SL	R^2	OW vs. SL	R^2
A. chacunda	37	SL = 33.924 OL + 8.7108	0.848	SL = 60.137OH + 23.838	0.7323	SL = 12323OW + 88.754	0.7441
D. acuta	37	SL = 27.104OL + 17.607	0.932	SL = 50.517OH + 13.756	0.7604	SL = 10265OW + 70.074	0.7838
D. elopsoides	40	SL = 19.679OL+ 60.741	0.752	SL = 32.729OH + 79.06	0.5327	SL= 10268OW + 101.95	0.7452
I. megaloptera	30	SL = 65.27 OL - 52.866	0.870	SL = 112.03OH - 91.71	0.8814	SL = 6808.4OW + 179.09	0.7862
I. melostoma	30	SL = 38.628 OL - 10.081	0.931	SL = 74.304OH - 9.4203	0.8581	SL = 8152.5OW + 111.78	0.8921
N. nasus	30	SL = 38.34 OL - 11.799	0.911	SL = 73.421OH - 13.194	0.7711	SL = 29051OW + 46.083	0.7767
S. gibbosa	40	SL = 18.216 OL + 61.873	0.848	SL = 39.006OH + 64.555	0.7787	SL = 14413OW + 97.935	0.7915
S. longiceps	30	SL = 14.601 OL + 88.486	0.891	SL = 33.655OH + 87.388	0.8421	SL = 20117OW + 93.422	0.8055
S. sindensis	40	SL = 42.678 OL - 2.6566	0.885	SL = 91.856OH - 5.5861	0.6837	SL = 32433OW + 68.046	0.7580
T. ilisha	30	SL = 27.913 OL + 118.84	0.799	SL= 40.081OH + 169.68	0.5069	SL= 13661OW + 171.46	0.6644

Table IV. - Relationship between otolith morphometric parameters and body weight (BW). Coefficient of determination (R^2) and sample size (N) are indicated. OL: otolith length, OH: otolith height, OW: otolith weight. All regressions were statistically significant at $p < 0.05$.

Species	N	OL vs. BW	R2	OH vs. BW	R2	OW vs. BW	R2
A. chacunda	37	BW = 51.38OL - 114.07	0.7248	BW = 90.08OH - 89.385	0.7242	BW = 18983OW + 6.0644	0.7782
D. acuta	37	BW = 13.014OL - 23.422	0.8339	BW = 24.528OH - 26.06	0.8335	BW = 4923.4OW + 1.5107	0.8577
D. elopsoides	40	BW = 12.481OL - 14.344	0.7042	BW = 22.313OH - 5.4105	0.5763	BW = 6768.8OW + 10.951	0.7536
I. megaloptera	30	BW = 208.31OL - 777.27	0.7314	BW = 353.12OH - 885.29	0.7982	BW = 24216OW - 85.408	0.9066
I. melostoma	30	BW = 55.137OL - 178.29	0.9103	BW = 104.06OH - 171.99	0.8599	BW = 11637OW - 4.3415	0.9287
N. nasus	30	BW = 22.41OL - 40.661	0.8416	BW = 42.484OH - 40.903	0.7618	BW = 17427OW - 7.4149	0.8246
S. gibbosa	40	BW = 11.307OL - 9.9642	0.7149	BW = 24.239OH - 8.3374	0.7701	BW = 8782.3OW + 12.685	0.7527
S. longiceps	30	BW = 8.102OL + 8.3271	0.6879	BW = 19.154OH + 6.9768	0.7615	BW = 11832OW + 9.5355	0.7779
S. sindensis	40	BW = 14.474OL - 22.332	0.7642	BW = 31.425OH - 23.64	0.687	BW = 10747OW + 1.8926	0.7145
T. ilisha	30	BW = 126.37OL - 307.92	0.5536	BW = 177.74OH - 68.275	0.4275	BW = 62126OW - 71.78	0.5893

cies of clupeids, which corresponds with the findings of Hunt (1992) in 8 selected species of the Northwest Atlantic Ocean. Similarly, Harvey *et al*. (2000) revealed that among 63 species of the Eastern North Pacific Ocean, the relationship between OL and SL was not significantly different between left and right otoliths for all but one fish, viz. *Anodontostoma chacunda*. Similar finding has also been reported on 4 species of Sciaenidae from the Southwest Atlantic Ocean, except for OH in white mouth croaker and OL in king weakfish (Waessle *et al*., 2003).

Relationship between otolith morphometric parameters and fish SL and BW for clupeid species studied were explained by exponential regression models which best fit the data distribution. Analyzing the morphometric relationships, it was concluded that OL and OW are good indicators of SL and BW in all species (Tabs III, IV). Only in *I. megaloptera* otolith height is better indicator of fish SL.

In some species the relationship between OL and SL may be dependent on the growth rate of the fish, as was reported for striped bass (Secor and Dean, 1989). Within each growing group, otolith and fish size are highly correlated. In its turn, the somatic growth rate is governed by the aquatic environment, food quality and quantity, internal patterns, etc. (Wright *et al*., 1990). Estimating size of consumed fishes from measurements of otoliths recovered in stomachs or feces may be biased because of partial or complete digestion of otoliths. Although a rough estimate of these errors may be obtained from controlled experiments, the amount of digestion may be species-specific, requiring numerous tests to document all forms of bias. There also may be differences between the sexes in the relationship between fish size and otolith size, something we did not test. Researchers using otoliths to determine number and size of fish eaten, therefore, should realize the limitations of this technique (Harvey *et al*., 2000).

Acknowledgements. - The authors are grateful to various colleagues associated with the sampling, especially Ali Salarpouri for his hard work providing many samples and also helping species identification. We also wish to thank the reviewers for their reviewing work and their useful comments and advices.

REFERENCES

ASSIS C.A., 2005. - The utricular otoliths, lapilli, of teleosts: Their morphology and relevance for species identification and systematic studies. *Sci. Mar*., 69: 259-273.

BÉAREZ P., 2000. - Archaïc fishing at Quebrada de los Burros, southern coast of Peru. Reconstruction of fish size by using otoliths. *Archaeofauna*, 9: 29-34.

BERRA T.M. & ADAY D.D., 2004. - Otolith description and age-and-growth of *Kurtus gulliveri* from northern Australia. *J. Fish. Biol*., 65: 354-362.

CASTEEL R., 1974. - Use of Pacific salmon otoliths for estimating fish size, with a note on the size of late Pleistocene and Pliocene salmonids. *Northwest. Sci*., 48: 175-179.

CASTEEL R., 1976. - Fish Remains in Archaeology and Paleo-environmental Studies. 180 p. New York: Academic Press.

FISCHER W. & BIANCHI G., 1984. - FAO Species Identification Sheet For Fishery Purposes Western Indian Ocean Fishing Area 51. Vols 1-5. Rome, Italy.

FITCH J.E., 1968. - Otoliths and other fish remain from the Timms Point silt (early Pleistocene) at San Pedro, California. *Los Angeles Cty. Mus. Contrib. Sci*., 146: 1-29.

FITCH J.E., 1969. - Fossil records of certain schooling fishes of the California current system. *CalCOFI Rep*., 13: 71-80.

FROST K.J. & LOWRY L.F., 1981. - Trophic importance of some marine gadids in northern Alaska and their body-otolith size relationships. *Fish. Bull*., 79: 187-192.

GAMBOA D.A., 1991. - Otolith size versus weight and body-length relationships for eleven fish species of Baja California, Mexico. *Fish. Bull*., 89: 701-206.

HARVEY T.J., LOUGHLIN R.T., PEREZ A.M. & OXMAN S.D., 2000. - Relationship between fish size and otolith length for 63 species of fishes from the Eastern North Pacific Ocean. 150 p. NOAA Technical Report NMFS.

HUNT J.J., 1992. - Morphological characteristics of otoliths for selected fish in the Northwest Atlantic. *J. Northw. Atl. Fish. Sci*., 13: 63-75.

NOLF D., 1985. - Otolithi Piscium. Handbook of Paleoichthyology. 145 p. Stuttgart: Gustav Fischer Press.

POPPER A.N., RAMCHARITAR J.U. & CAMPANA S.E., 2005. - Why otoliths? Insight from inner ear physiology and fisheries biology. *Mar. Freshw. Res*., 56: 497-504.

SECOR D.H. & DEAN J.M., 1989. - Somatic growth effects on the otolith-fish size relationship in young pound- reared striped bass, *Morone saxatilis*. *Can. J. Fish. Aquat. Sci.*, 46: 113-121.

TEMPLEMANN W. & SQUIRES H.J., 1956. - Relationship of otolith lengths and weights in the haddock, *Melanogrammus aeglefinus* (L.), to the growth of the fish. J. *Fish. Res. Board. Can*., 13: 467-487.

TROUT G.C., 1954. - Otolith growth of the Barents Sea cod. *Rapp. P-V. Reun. Cons. Int. Explor. Mer*., 150: 297-299.

WAESSLE J.A., LASTA C.A. & FAVERO M., 2003. - Otolith morphology and body size relationships for juvenile Sciaenidae in the Rio de la Plata estuary. *Sci. Mar*., 67: 233-240.

WRIGHT P.J., METCALFE N.B. & THORPE J.E., 1990. - Otolith and somatic growth rates in Atlantic salmon parr, *Salmo salar* (L.): evidence against coupling. *J. Fish. Biol*., 36: 241-249.

WYLLIE-ECHEVERRIA E.T., 1987. - Relationship of otolith length to total length in rockfishes from northern and central California. *Fish. Bull*., 85: 383-387.

Reçu le 17 mars 2011.
Accepté pour publication le 14 mai 2012.